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A Provenance Trial of Sitka Spruce in the Boreal Forest

J. Peter Hall

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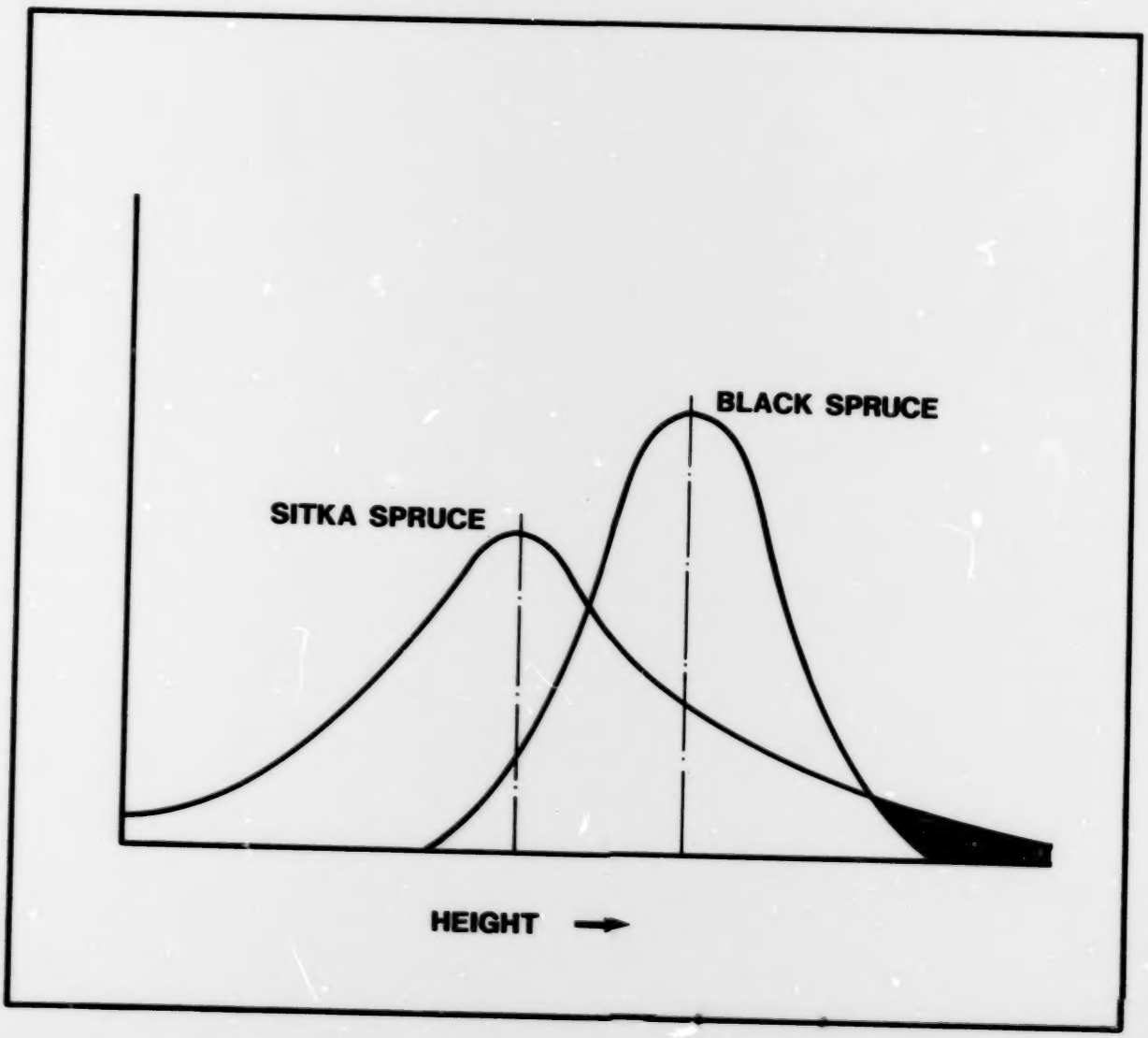

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A PROVENANCE TRIAL OF SITKA SPRUCE IN THE BOREAL FOREST

by J. Peter Hall

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ABSTRACT

A trial comparing the growth of 12 provenances of Sitka spruce with that of local black and white spruce was measured when the trees were 20 years old. Sitka spruce had poorer survival and growth and greater winter damage than the native black and white spruce. However, in three of the plantations in western Newfoundland, the tallest trees in the plantations were Sitka spruce. There are indications that a land race of Sitka spruce may be developing. Implications for forest management are discussed.

RÉSUMÉ

Un test de comparaison entre 12 provenances d'épinettes de Sitka ainsi que des épinettes noires et des blanches d'origine locale a été fait sur des sujets de 20 ans. La survie et la croissance des épinettes de Sitka étaient inférieures à celles des autres et les dommages par le froid supérieurs. Dans trois plantations de l'ouest de Terre-Neuve, cependant, les plus hauts arbres étaient des épinettes de Sitka. Il semble possible qu'une race locale d'épinettes soit en voie d'apparition. Les conséquences sur le plan de laménagement forestier sont étudiées.

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A PROVENANCE TRIAL OF SITKA SPRUCE IN THE BOREAL FOREST

by

J. Peter Hall

INTRODUCTION

The boreal forest in Newfoundland consists primarily of balsam fir (Abies balsamea (L.) Mill.) and black spruce (Picea mariana (Mill.) B.S.P.) and small quantities of other boreal softwoods and hardwoods. Currently large-scale reforestation programs are in place and the opportunity exists to diversify the species mixture and therefore grow products to meet the various demands of wood users.

Trials of exotic species have been conducted for many years in Newfoundland (Hall 1982). Early tests of Sitka spruce (P. sitchensis (Bong.) Carr.) on the barren lands of eastern Newfoundland were promising and stimulated interest in its use elsewhere on the Island (Nickerson et al. 1964). Sitka spruce, a native of coastal western North America, was first introduced in the UK as early as 1831 and has been widely planted throughout northwestern Europe during the last hundred years (Roche and Fowler 1975). It has a wide range in its native habitat; 2500 km south to north and from sea level to 900 m though it is restricted to the coastal fog belt (Fowells 1965). While it is native to a milder climate than boreal Newfoundland, it will grow under more severe conditions and is also resistant to salt exposure prevalent in Maritime climates (Roche and Fowler 1975). It has been reported to have the ability to survive in the severe habitat of nunataks from which it

re-established itself following the Wisconsin glaciation period (Daubenmire 1968).

Variation in Sitka Spruce

It is common for species which have a wide geographic range to be quite variable in terms of adaptation to differing environments and habitats (Wright 1976). The literature is not extensive on the genetics of Sitka spruce and there is a need for comprehensive provenance research (Roche and Fowler 1975). Clinal variation exists on cessation of growth, entering of dormancy, formation of buds and dates of flushing (Roche and Fowler 1975; Burley 1966). Wood properties and resistance to wind and salt are also variable. It has been shown that nutrient use efficiency varies from 10 to 30 percent among clones and is under genetic control (Sheppard and Cannell 1985). This property could be used to select low nutrient demanding clones for nutrient poor sites.

Where the geographical range of Sitka spruce is sympatric with that of white spruce (*Picea glauca* (Moench) Voss.) the species hybridize freely (Roche and Fowler 1975). Artificial Sitka-black spruce hybrids have also been developed (Roche and Fowler 1975; Fowler 1983). There is the possibility of selecting heterotic individuals from inter-specific hybridization for use in forest management.

Value of Seed Source Trials

The greatest and fastest gains in forest improvement can be made using the proper seed sources (Zobel and Talbert 1984). It is

necessary to use the optimal seed source for maximum potential growth, wood quality, frost tolerance and resistance to insects and diseases (Yeatman 1976, Yeatman and Morgenstern 1978). Outbreeding populations normally carry a reserve variability which is not expressed in normal habitats but when transferred to a new environment, adaptive qualities are expressed in the new habitat (Heslop-Harrison 1959). The more extreme the difference between the habitats, the more pronounced the adaptation. Adaptive variation has been reported to occur in Sitka spruce (Burley 1966). Selection of seed sources for planting should be based on the environmental conditions prevailing at the planting site. A provenance study locates the populations which are best adapted to local conditions (Barner 1978). The objectives of this study were to evaluate various seed sources of Sitka spruce in the major commercial forest areas in Newfoundland.

METHODS

Seed Sources Tested

A total of 12 provenances ranging from Oregon to Alaska were used. A comparison of climatic conditions in Newfoundland with those of British Columbia indicated that the climate in north-central coastal region best matched that of Newfoundland. Thus the largest numbers of provenances were sampled near that latitude (Nicholson and Tricco 1970). To evaluate the performance of an exotic the normal practice is to

compare its growth with that of local species which would usually be used in reforestation (Zobel and Talbert 1984). Therefore sources of black spruce and white spruce were also planted (Fig. 1, Table 1).

Half the seed of these provenances was sown in 1965 and half in 1966 at the Acadia Forest Experiment Station in central New Brunswick and the seedlings were shipped to the Pasadena nursery in western Newfoundland as 2-0 stock. The stock was then grown to 2-2 stock and was planted in 1969 and 1970.

Plantation Establishment and Design

Nine plantation sites (Figure 2) were selected in order to sample the various parts of the productive forest areas of the Island (Rowe 1972). Seven plantations were planted during May, June 1969 and the remaining two (Crabbes River and New Bay Pond) in May-June 1970 (Nicholson and Tricco 1970). All sites had been cut or burned shortly before planting and weed competition did not appear to be a serious problem. The sites were cleared of slash, and during planting various weeds and balsam fir advance growth were removed. Planting of all plantations took place during late May to early June as soon as roads were passable (Table 2). Previous forest types had been productive balsam fir or black spruce except for the Mobile plantation. This site had been deforested many years previously and was unstocked to commercial species, but was covered in patches of mountain alder (Alnus crispa Ait.) and Kalmia (K. angustifolia L.). The site was ploughed using a Parkgate Tine Plough towed by a D-6 tractor (Salter and Evans 1976), which broke up the

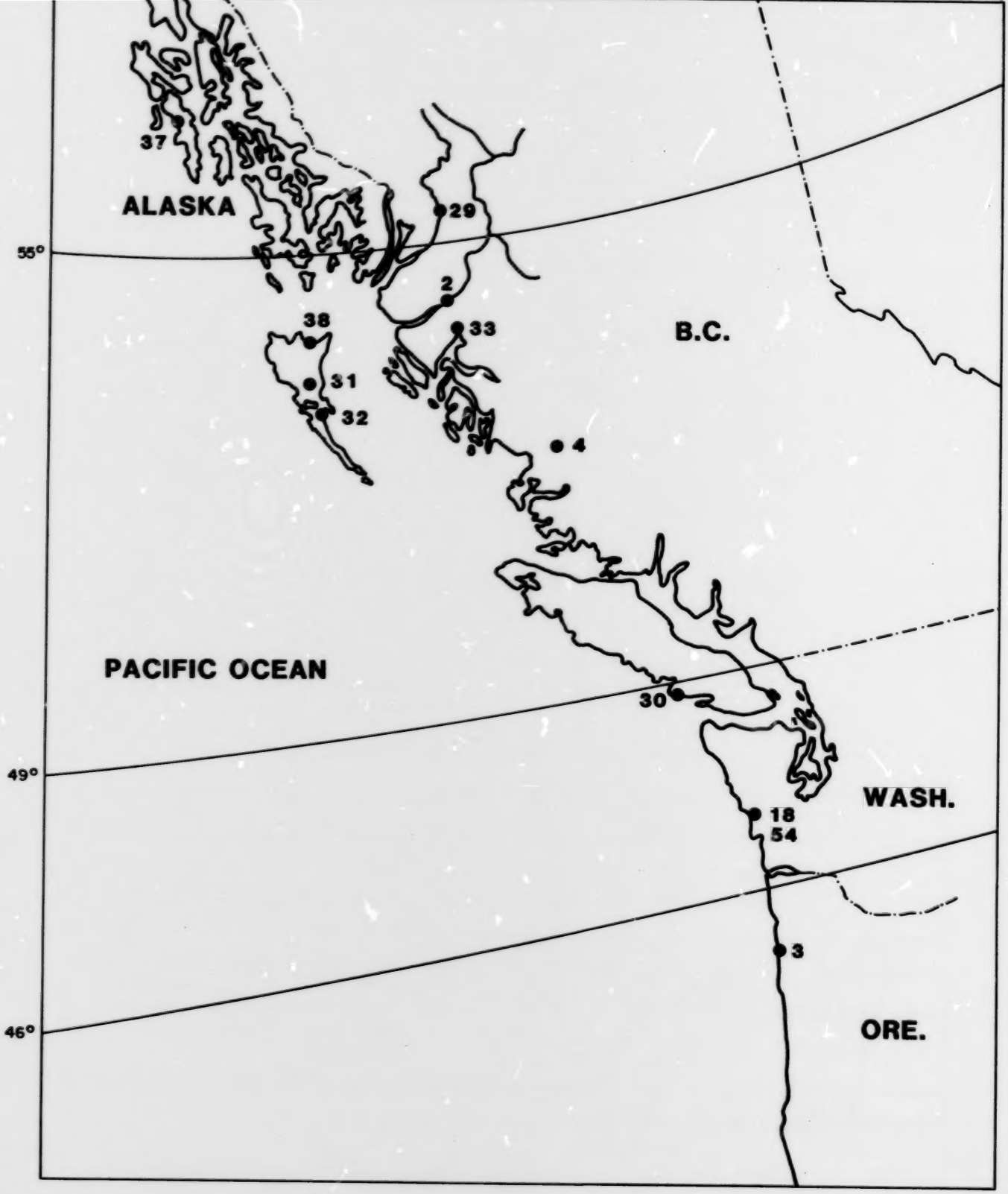

FIGURE 1. ORIGIN OF THE SITKA SPRUCE PROVENANCES

Table 1. Origin of seed sources for the Sitka spruce provenance trial.

Species	Seedlot number	Origin		Elevation (m)	Description
		Latitude	Longitude		
Sitka spruce	2	54°45'	128°45'	-	Skeena River Valley, B.C.
" "	3	44°46°	124°	-	Oregon, precise location unknown
" "	4	52°22'	126°45'	60	Bella Coola, B.C.
" "	18	47°	124°	<150	Aberdeen, Washington, U.S.A.
" "	29	55°	129°	-	Nass River Valley, B.C.
" "	30[a]	48°50	125°15'	-	Klanawa River, Vancouver Island, B.C.
" "	31	53°30[1]	132°15'	150	Gold Cr., Yakaum R., Graham Island, Queen Charlotte Islands, B.C.
" "	32	53°05'	132°05'	75	Pallant Cr., Cumshewa Inlet, Moresby Island, Queen Charlotte Islands, B.C.
" "	33	54°03'	128°39'	60	Kitimat, B.C.
" "	37	57°05'	135°20'	<150	Sitka, Alaska, U.S.A.
" "	38	54°	132°20'	<150	Masset, Queen Charlotte Islands, B.C.
" "	54	47°	124°	-	Aberdeen, Washington, U.S.A.
Black spruce	59	48°45'	56°	100	West Branch Lake, Badger, Nfld.
White spruce	439	45°59'	66°22'	60	'Bull Pasture', Acadian For. Exp. Stn., Fredericton, New Brunswick.

[a]Seed collected from one mother tree.

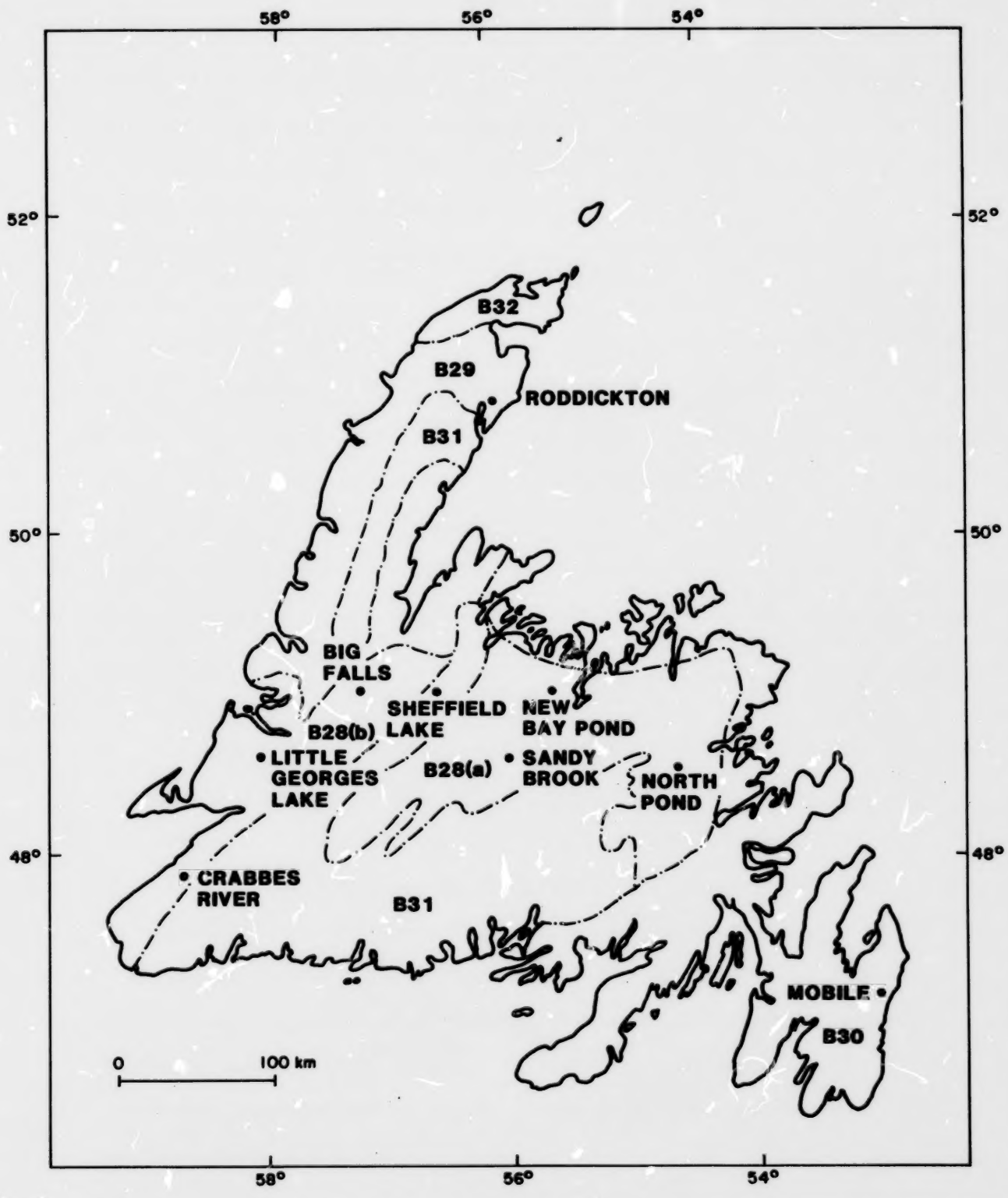

FIGURE 2 LOCATION OF SITKA SPRUCE PROVENANCE PLANTATIONS

Table 2. Description of plantations.

Plantation	Location		Elevation (m)	Forest section	Date planted	Site history
	Latitude	Longitude				
Crabbes River	48°08'	58°38'	180	B.28b	20-26 May	Cut 1968
Little George's Lake	48°46'	58°01'	200	B.28b	16-20 June	Cut 1968
Big Falls	49°16'	57°09	200	B.28b	21-23 May	Cut 1968
New Bay Pond	49°13'	55°34'	150	B.28a	3-6 June	Cut 1968
Sandy Brook	48°46'	56°01'	210	B.28a	8-11 June	Cut, burned 1967
North Pond	48°42'	54°32'	90	B.28a	28 May-2 June	Cut 1957 Burned 1961
Roddickton	50°56'	56°12'	110	B.29	10-12 June	Cut, burned 1967
Sheffield Lake	49°21'	56°35'	290	B.31	27 May-3 June	Cut 1968
Mobile	47°15'	52°55'	120	B.30	25-28 June	Ploughed 1967

surface layer of raw humus and provided a mixture of humus and soil which facilitated planting, early seedling survival and growth.

Each plantation consists of eight replicates of 12 provenances planted in 16-tree plots. Planting was by the pit planting method with a spacing of 1.8 metres. Thus at each plantation there are 128 trees of each provenance and each plantation contains 1536 trees. Each plantation is surrounded by two rows of trees of provenance 2 (Nicholson and Tricco 1970). The design is a randomized complete block (Steel and Torrie 1960).

Every plantation contains black spruce (seed source 59) and eight of the Sitka spruce provenances: 2, 4, 18, 29, 31, 32, 33 and 38. The remaining sources - white spruce 439 and Sitka spruce 3, 30 and 54 - were distributed randomly among the plantations according to the number of seedlings available.

Remeasurements

After the first growing season (1969) survival was assessed in the seven plantations established that year. Those at Sheffield Lake and Roddickton had the best survival; North Pond and Mobile, the poorest. In the spring of 1970 dead trees were replaced in all plantations except those at North Pond and Mobile. No trees were replaced in the plantations planted in 1970. Survival was assessed in all plantations over a period between September 1981 and October 1982 when the plantations were between 12 and 14 growing seasons from planting. The latest survival counts were done when the trees were 20 years from seed and had 16 growing seasons in the field.

Frost damage was assessed in seven plantations[1] after one growing season. The least affected provenances were 2, 33, 4, 29, and 37 (Nicholson and Tricco unpub. data). The amount of winter damage was assessed again in 1974 when the plantations were 9 or 10 years from seed (Khalil 1977).

Data were analysed using Analysis of Variance and Duncan's[1] New Multiple Range (NMR) test (Steel and Torrie 1960).

Height growth was measured in October 1974 when seven plantations were 10 years from seed and two (Crabbes River, New Bay Pond) were 9 years from seed. When all trees were 20 years old (in 1984 and 1985) the trees were measured for total height and diameter at breast height.

RESULTS AND DISCUSSION

Survival

Survival was excellent after one growing season in the field with the exotic Sitka spruce generally having better survival than the native black or white spruce (Table 3). Among plantations Crabbes River, Roddickton and Sheffield Lake had the best survival, New Bay and North Pond the poorest. Provenance 3 had the lowest survival (83.2%) and as it was the most southerly of the provenances, suffered the most from frost damage and winter desiccation. The clinal variation in growth cessation

[1]The 'poor quality' plantations, North Pond and Mobile, were not assessed.

Table 3. Percentage survival after one growing season.

Plantation		Percentage Survival		
Location	Survival	Black spruce (59)	White spruce (439)	Sitka spruce (range)
Crabbes River	99.2	99.2	-	96.1-100.0
Little George's Lake	95.8	93.8	98.4	89.1-100.0
Big Falls	97.9	95.3	96.1	98.4-100.0
New Bay Pond	89.8	99.2	-	88.3-100.0
Sandy Brook	95.9	96.1	94.5	92.2-99.2
North Pond	93.1	100.0	100.0	81.2-99.2
Roddickton	99.7	100.0	-	99.2-100.0
Sheffield Lake	99.5	100.0	-	97.7-100.0
Mobile	91.9	67.3	82.8	82.0-98.4
Mean	96.8	94.2	94.4	83.2-99.1

and bud set which causes southerly provenances to continue growth into the fall and begin growth earlier in the spring, leaves them more susceptible to frost damage (Roche and Fowler 1975).

A complete survival count was done when the trees had been 16 growing seasons in the field (20 years from seed). Survival averaged 58.4% (Table 4). Survival among plantations ranged from 45 to 69% with no overall superiority in any forest zone. The best survival was at Mobile, the one most exposed to wind and salt. The resistance of Sitka spruce to salt and exposure was once again demonstrated. Survival was

Table 4. Percentage survival of each provenance at each plantation at age twenty (16 growing seasons).

Provenance		Survival Each PlantationΨ								
Number	Survival	Crabbes River	Little George's Lake	Big Falls	New Bay Pond	Sandy Brook	North Pond	Roddickton	Sheffield Lake	Mobile
59	74.4	74.2	62.7	82.1	87.5	72.7	85.9	85.9	80.5	39.1
439	63.9	-	75.8	77.4	-	82.8	46.9	-	-	36.7
2	58.2	39.1de	41.4b	64.9c	57.8c	35.2d	81.3a	62.5c	57.8b	84.4
3	36.9	-	35.2d	-	-	28.9	19.5	-	-	64.1
4	51.2	37.5ae	38.3c	66.4bc	51.6b	40.6c	66.4b	47.7	45.3e	67.2d
18	56.5	47.7	35.9d	72.7	61.7	40.6c	52.3	62.5c	55.5c	79.7a
29	60.3	45.3b	46.1	68.8a	59.4bc	46.1ab	78.1	61.7c	56.2bc	81.3a
30	65.3	49.2a	-	67.2ab	84.4	-	-	62.5c	63.3a	-
31	55.5	32.0	39.8bc	55.5e	64.8a	61.2	58.6c	63.3c	53.1d	71.9c
32	55.6	50.0a	51.6a	54.7e	54.7	35.2d	57.0c	57.0d	56.2bc	87.5
33	59.4	41.4cd	57.8	66.4bc	66.4a	43.8b	66.4b	65.6ab	53.1d	73.4bc
37	56.9	41.4cd	55.5	-	60.2b	46.9a	82.0a	61.7d	45.3e	68.8d
38	58.7	43.8bc	52.3a	59.4d	60.9b	43.8b	64.1	64.1bc	64.8a	75.0b
54	58.1	43.0bc	-	57.8d	71.1	-	-	66.4a	52.3d	-
Mean	58.4	45.4	49.3	66.1	65.0	48.0	63.2	62.9	57.0	68.8

Ψ Percentages followed by the same letter, in each plantations, are not significantly different from each other.

poorest in the plantations where competition from balsam fir regeneration was high (Crabbes River and Little George's Lake) and where Kalmia became dominant after plantation establishment (Sandy Brook). The plantations at Roddickton and North Pond were established on burned cutovers where competition was less, hence the increased survival. At Big Falls where there was almost no regeneration following cutting, survival was above average.

In all plantations, except Mobile, survival of native spruce was better than that of Sitka. Among the Sitka there were few overall differences except for provenance 3. Survival of Sitka spruce was good at Mobile however, which has the warmest winter temperature of the nine sites. The best surviving Sitka was #30 from Vancouver Island, the latitude most closely resembling those of the test sites.

Differences among provenances within the plantations were significant in all cases and in five plantations differences among replicates were also significant (Appendix I). The data indicate that not only are provenance effects large but site differences within the plantations are also large. There are few trends among the Sitka spruce provenances except for the poor survival of the Oregon provenance #3. The northern-most one which might have been expected to have survived the best had high survival only at North Pond and was average or poorer at other sites. Survival trends did not have a clinal pattern but the survival pattern indicates possible presence of adaptive ecotypes as has been described previously (Burley 1966).

Some mortality can be traced to winter damage and infection by Armillaria mellea as reported by Khalil (1977). Generally, mortality was higher in those plantations which had higher levels of infection. Frost damage was higher in the more southerly provenances; this weakened the trees and made them more susceptible to damage by Armillaria (Khalil 1977, Appendix II). Armillaria damage after six years in the field was highest at Crabbes River which has lowest 16-year survival, and was lowest at Mobile which has the highest 16-year survival (Khalil 1977, Table 4). There is a trend of higher survival coupled with lower infection levels.

Winter damage showed a different trend. Plantations with low levels of frost damage also had low survival. As in most trials of exotic species in Newfoundland most mortality occurred within one or two years of planting (Hall 1982). Trees surviving the first few winters are largely frost hardy and are only slightly damaged in later years.

A mortality count was made between 1981-82 after 12-14 growing seasons. When tested, survival was not statistically different from survival after 16 growing seasons. The overall difference was only 1.5% and at the last remeasurement, trees which had recently died were often small and bushy. It can be inferred from the data that there have been strong selection pressures exerted by the climatic conditions in the plantation areas. Damage has also occurred from Armillaria root rot which is reported to be more serious on planted than on seeded stock, and on exotics compared to native species (Singh and Richardson 1973). This increased damage on exotics undoubtedly reflects the stress of exotics

adjusting to a new environment and to some extent planting shock. The large decrease in survival from the first (Table 3) to the 12th to 14th growing seasons indicates that several years are required for the various seedlots to become adapted to their new environment. Moreover the small change over the last 2-4 years further indicates that the process may be nearly complete. There is the possibility that a land race is evolving, i.e. that a proportion of the population is expressing itself in a manner different from its origin. It has been suggested that this can occur in Sitka spruce (Roche and Fowler 1975; Heslop-Harrison 1959). Sitka spruce originates in areas of mild climate but is known to be able to survive in harsh climates (Daubemire 1968) (Nickerson et al. 1964, Roche and Fowler 1975).

Height Growth

Variation in height growth was statistically significant at the 0.995 level in all plantations (Appendix I). However, variation among replicates was also significant in eight of nine plantations, indicating that site variation within the plantation was sufficient to affect height growth.

There was wide variation among plantations reflecting differences in site quality. Growth was best at Crabbes River, Little George's Lake and Sheffield Lake but poorest at North Pond and Mobile (Table 5). Poor growth at North Pond can be attributed to the stressed conditions of the trees shortly after planting followed by the invasion of considerable natural spruce and hardwood regeneration on the site (Nicholson and Tricco 1970). At Mobile the exposure of the site to salt and onshore

Table 5. Average total height, all provenances, all plantations, twenty years from seed.

Provenance		Average Total Height (cm)								
Number	Mean	Crabbes River	Little George's Lake	Big Falls	New Bay Pond	Sandy Brook	North Pond	Roddickton	Sheffield Lake	Mobile
59	332	442aΨ	362ab	291	325	304a	276	356	407	96c
439	247	-	376a	208ab	-	287a	108a	-	-	110c
2	221	393abc	310bc	193ab	221abc	178b	91ab	288a	324c	138ab
3	123	-	184	-	-	84e	52d	-	-	130abc
4	207	360bcde	314abc	179bcd	233a	154bc	87bc	220bc	351bc	118abc
18	164	330def	244d	139d	196bcd	87c	70bcd	123f	220e	118abc
29	221	383bcd	301bc	186bc	231ab	191b	92ab	246b	388ab	120abc
30	213	337cdef	-	150cd	214abcd	-	-	135f	258de	-
31	189	375bcd	301bcd	153cd	211abcd	132cd	69cd	199cd	291d	116bc
32	192	362bcd	310bc	163cd	186cd	106de	72bcd	166e	298d	103c
33	239	400ab	328abc	224a	215abcd	179b	81bc	281a	391ab	144a
37	181	291f	280cd	-	179d	134cd	70cd	207cd	291d	112abc
38	206	392abc	340abc	175bcd	199abcd	122cde	78bc	186de	305cd	120abc
54	186	306ef	-	127d	194cd	-	-	123f	220e	-
Mean	216	368	308	186	220	181	94	214	315	120
Mean‡	-	105	100	95	91	82	51	107	106	58

Ψ Means in the same column followed by the same letter are not significantly different from each other at probability level 0.95.

‡ Mean height at age 10 (Khalil 1977).

winds prevented height growth even though survival was good. Plantations of other species on the Mobile site showed the same trend (Hall 1986). At two other plantations (Big Falls, Sandy Brook) the presence of a Kalmia understory reduced growth. The best growth occurred on sites which had evidence of previous high productivity. The northernmost plantation (Roddickton), had average growth rate. This was better than expected for sub-arctic conditions (50°56'N) and is explained by the fact that the underlying parent material is limestone which makes the soil less acidic than most Newfoundland soils.

In comparing provenances, it is obvious that native black spruce and white spruce have outgrown all exotics. In eight of the nine plantations the native species are tallest, and in five of the eight they are significantly taller than all exotic Sitka spruce. At Mobile exposed conditions have prevented appreciable height growth, but the Sitka spruce has adapted better to exposure than the native spruces. This has been observed for other plantations at Mobile (Hall 1986) and the tolerance of exposure by Sitka spruce is well known in its native range (Daubenmire 1968). In the forested parts of the Island the better adapted black and white spruce have, on average, outgrown Sitka spruce.

The five plantations where native spruce(s) had significantly better growth were:

Big Falls	**where the best Sitka provenances were**	**33, 2, 29, 4**
New Bay Pd.	**" " " " " "**	**4, 29, 2, 33**
Sandy Brook	**" " " " " "**	**29, 33, 2, 4**
North Pond	**" " " " " "**	**29, 2, 4, 33**
Roddickton	**" " " " " "**	**2, 33, 29, 4**

The three plantations where native spruce(s) did not have signif icantly better growth were:

Crabbes River	**where the best Sitka provenances were**						**2, 33, 38, 29**
Little George's Lake	"	"	"	"	"	"	**4, 33, 38, 32**
Sheffield Lake	"	"	"	"	"	"	**29, 33, 4, 2**

These same groups of provenances performed well at Mobile. The southerly provenances were not unduly affected by exposure showing that trees from all over the range can adapt to exposure.

Growth of the most northerly provenance was poorer than that of the more southerly ones. There are some indications of growth rate latitude clinal variation but localized temperatures probably have an equally important effect on growth (Roche and Fowler 1975). For instance provenance 37 originates from a much lower degree day area (hence colder than others at a similar latitude) but does not grow as well as the other provenances at the same latitude. Provenances which combine good growth rate and resistance to autumn frosts exist in Sitka spruce and apparently can be found in many parts of the range (Burley 1966).

Sitka spruce provenances in Newfoundland exhibit clinal variation as shown by the correlation of latitude of origin with winter damage and with height growth. Winter damage at age 9 and 10 was closely related to latitude of origin in all plantations except Mobile and North Pond. Here most trees were not tall enough to be above the snow line and so were not exposed to winter damage.

Clinal variation in growth of Sitka spruce has been reported previously (Fowler and Roche 1975, Burley 1966). There is evidence of clinal variation in height growth in this provenance trial (Table 6). In plantations where there is a weak relationship at age 10 it becomes stronger at age 20, except at New Bay Pond and Crabbes River. These plantations were heavily damaged by spruce budworm (Choristoneura fumiferana Clem.) attacks in 1977-79 and this may have disrupted growth patterns so a to override the effects of latitude. The greatest change is at North Pond where the relationship strongly reverses itself for no apparent reason. The change was least at Roddickton which was unaffected by competition and also had no budworm damage. The weak correlations at age 10 may reflect the nursery stage with the trees adjusting to field conditions which some individuals and provenances do at different rates. Where the differences between the black spruce and the Sitka spruce are greatest (Big Falls, Sheffield Lake, Roddickton) latitude effects are also large.

To summarize height growth; the native black spruce and in some cases white spruce outgrew Sitka spruce in eight of the nine plantations. In five of these eight the black spruce was significantly better than all of the exotic Sitka spruce. Although black spruce grew better than Sitka spruce in the three plantations of best growth, the differences between black and Sitka were not significant. In these plantations the best growing Sitka spruce provenances were:

Table 6. Correlation coefficients between latitude of origin and height at age 10 and age 20.

Plantation Location	Correlation Coefficient Ht. at age 9/10	Ht. at age 20
Western B.28b		
Crabbes River	.471 N.S.	.395 N.S.
Little George's Lake	.429 N.S.	.799 *
Big Falls	.902 *	.787 *
Central B.28a		
New Bay Pond	.505 N.S.	.093 N.S.
Sandy Brook	.217 N.S.	.705 *
North Pond	-.448 N.S.	.635 *
Northern B.29		
Roddickton	.741 *	.722 *
North Central B.31		
Sheffield Lake	.776 *	.718 *
Eastern B.30		
Mobile	.592 *	-.085 N.S.
Mean	.465	.530

* Statistically significant at P = 0.95.

2 - Skeena River Valley, B.C.

4 - Bella Coolla, B.C.

29 - Nass River Valley, B.C.

33 - Kitimat, B.C.

These provenances were among the best Sitka provenances reported by Khalil (1977).

Diameter Growth

Variation among provenances in diameter growth was also statistically significant in all plantations (Appendix I). This variation in diameter among replicates was less than for height, suggesting that site variation among replicates affected diameter less than it did height growth.

Differences in diameter among provenances within plantations are not as pronounced as height differences (Table 7). Provenances and plantations in which height growth was best had the best diameter. In general, where growth was good the Sitka were not significantly different from black spruce (Crabbes River, Little George's Lake and Sheffield Lake). In the other plantations (except for Mobile) black spruce growth is much better than the Sitka.

Diameter and height growth patterns differ because diameter is affected more than height by stand spacing and degree of competition. The proximity of nearby trees and the degree of branchiness affect both diameter and provenance to an unknown degree. It is therefore difficult to assess suitability of provenances based on this parameter. A listing of

Table 7. Average diameter, all provenances, all plantations, twenty years from seed.

Provenance		Average Diameter (cm)								
Number	Mean	Crabbes River	Little George's Lake	Big Falls	New Bay Pond	Sandy Brook	North Pond	Roddickton	Sheffield Lake	Mobile
59	4.5	6.8aΨ	5.0a	3.5	4.4	4.0	2.9	5.0	6.1a	.2a
439	3.0	-	5.6a	2.2a	-	3.7	0.4a	-	-	.3a
2	2.6	6.6ab	4.3a	1.9ab	2.4abc	1.5	0.1b	3.8a	5.3	.5a
3	.6	-	1.5b	-	-	0.1b	0	-	-	.5a
4	2.2	5.6abc	4.2a	1.7abc	2.5ab	1.0	0.1b	2.2c	4.6	.4a
18	1.2	4.7cd	2.6ab	0.5d	1.6(c)‡d	0.1b	0	0.2g	2.0d	.3a
29	2.6	6.3ab	4.3a	1.8abc	2.6a	1.9	0.1b	2.9b	6.0	.4a
30	2.2	5.2bcd	-	1.0cd	2.0abcd	-	-	0.6fg	2.9	-
31	1.9	6.4ab	4.5a	1.1bcd	2.1abcd	0.5a	0.1b	1.7cde	4.1c	.3a
32	2.1	6.4ab	4.7a	1.4bc	1.7bcd	0.2	0.2a	1.1(e)f	4.2bc	.2a
33	2.9	6.4ab	4.9a	2.5a	2.1abcd	1.7	0.1b	3.4ab	6.1a	.9
37	1.9	4.6cd	4.1a	-	1.5d	0.8	0	2.1cd	4.3b	.2a
38	2.2	6.2ab	4.9a	1.7abc	1.8(a)bcd	0.5a	0	1.5(c)de	4.0c	.3a
54	1.6	4.1d	-	0.5d	1.6(c)d	-	-	0.5(f)g	2.0d	-
Mean	2.4	5.8	4.3	1.7	2.2	1.6	0.3	2.2	4.3	0.4

Ψ Means in the same column followed by the same letter are not significantly different from each other at probability level 0.95.

‡ Letters enclosed in parentheses indicate that the mean is on the borderline between significance and nonsignificance.

the best Sitka provenances shows a trend similar to that of height with the similarity being greater where overall growth rate is poorer. In the three faster-growing plantations where black Sitka differences were not significant;

Crabbes River	**the best Sitka spruce provenances were**						**2, 4, 31-32-33**
Little George's Lake	"	"	"	"	"	"	**33, 38, 32, 31**
Sheffield Lake	"	"	"	"	"	"	**33, 29, 2, 4.**

In the remaining slower growing plantations where black outgrew Sitka by a wide margin differences were statistically significant;

Big Falls	**the best Sitka spruce provenances were**						**33, 2, 29, 4-38**
New Bay Pond	"	"	"	"	"	"	**29, 4, 2, 3-31**
Sandy Brook	"	"	"	"	"	"	**29, 2, 33, 4**
North Pond	"	"	"	"	"	"	**2-4-29-31-33**
Roddickton	"	"	"	"	"	"	**2, 33, 29, 4.**

Land Race in Sitka Spruce

The concept of 'land race' as defined by Zobel and Talbert (1984) is a "population of individuals that has become adapted to a specific environment in which it has been planted" (p. 89). Using a well-adapted land race can also result in large and rapid gains in forest improvement. In both Norway spruce (*P. abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) land races have developed when these species have been planted as exotics. If such a race were to develop in Sitka spruce planted under the relatively harsh boreal forest conditions in Newfoundland then significant gains could be made in forest improvement.

Normally, land races develop over long periods of time and several generations are required. There is evidence that Sitka spruce in Denmark has developed land races which are adapted to the local environment (Cf. Roche and Fowler 1975). A nutritional form of land race has also been described (Sheppard and Cannell 1985). The value of a land race is that it enables the forest manager to enhance productivity using a population (usually of exotics) among which the superior individuals have been proven successful in their new environment. This population forms the base population from which seed will be grown to provide seed orchard material for breeding program.

The data from this study show that the growth of black spruce on average was generally superior to that of Sitka spruce. However, it was obvious at the time of measurement that in some plantations the tallest trees in the plantations were invariably Sitka spruce. These 'superior' trees were found in all provenances except 3, 30 and 54. To compare the growth of these trees with black spruce, the tallest trees in each replicate of the three best plantations were compared (Appendix III). The three plantations tested were Crabbes River, Little George's Lake and Sheffield Lake. In some replicates two or more provenances of Sitka spruce had trees taller than black spruce (Appendix III). This is evidence that on highly productive sites in western Newfoundland a sub-population or land race of Sitka spruce has developed. A strong selection pressure by climate has exerted itself on this introduced population and whereas most trees died or grew slowly, some of the genetic variability was expressed in superior

phenotypes which have grown faster than the native adapted black spruce. This expression of adaptability has been noted elsewhere for other species and to some extent for Sitka spruce (Heslop-Harrison 1959, Roche and Fowler 1975). In a reforestation program growth rate is very important, but resistance to insect and disease damage and wood quality are of equal value (Zobel and Kellison 1978). Trees in this study have demonstrated good growth and adaptability to damaging factors, wood quality has yet to be determined.

CONCLUSIONS

1. Average survival and growth rate was better for native black spruce (and occasionally) white spruce than Sitka spruce in eight of the nine plantations.
2. In one plantation, on barren heathlands (Mobile), Sitka spruce was superior in survival and growth but exposure conditions are so severe that no merchantable trees have developed or are likely to.
3. There was wide variation in survival and growth of Sitka spruce among plantations and among provenances within plantations.
4. In the eight plantations on productive forest sites the four best Sitka spruce provenances were:

   2 - Skeena River Valley, 54°45'N, 128°45'W

   4 - Bella Coolla, 54°22'N, 126°45'W elev 60 m

   29 - Nass River Valley, 55°N, 129°W

   33 - Kitimat, B.C. 54°03'N, 128°39'W, elev 60 m

5. There is evidence that a land race of Sitka spruce is developing in western Newfoundland. It may be possible to increase productivity by using faster growing individuals in a reforestation program. This would require a program of selection and breeding of well adapted individuals and the production of superior planting stock for reforestation.

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Appendix I. Calculated F values for Sitka spruce provenances and replicates for survival, height and diameter in all plantations.

Plantation	Survival		Height		Diameter	
	Provenances	Replicates	Provenances	Replicates	Provenances	Replicates
Crabbes River	2.55**[a]	5.84***	7.24***	6.03***	5.70***	3.97*
Little George's Lake	4.76***	6.20***	7.50***	2.51*	6.50***	1.75 N.S.
Big Falls	2.23*	4.15***	14.74***	25.33***	11.02***	22.72***
New Bay Pond	3.06*	1.72 N.S.	12.10***	9.81***	11.52***	11.42***
Sandy Brook	6.83***	1.03 N.S.	31.09***	3.17***	17.34***	2.46*
North Pond	12.55***	6.23***	81.68***	17.29***	84.21***	7.69***
Roddickton	2.46*	1.73 N.S.	45.36***	1.31 N.S.	43.49***	1.28 N.S.
Sheffield Lake	4.90***	3.16***	16.38***	6.96***	18.62***	8.11***
Mobile	6.74***	1.26 N.S.	3.09***	4.61***	2.17*	9.33***

[a] Significant at P = 0.95, ** at 0.99, *** at 0.995.

Appendix II. Percentage of seedlings winter damaged after one growing season, all provenances in seven plantations.

Povenance Number	Damage after 1 year	Percentage Damage in Each Plantation						
		Crabbes River	Little George's Lake	Big Falls	New Bay	Sandy Brook	Roddickton	Sheffield
59	0.4	1.6	0	0	0	0	0	1.6
439	1.0	-	0	1.6	-	1.6	-	-
2	2.1	1.6	0.8	0.8	2.3	3.1	6.2	0
3	47.7	-	40.6	-	-	54.7	-	-
4	7.6	6.2	2.3	2.3	7.0	18.0	16.4	0.8
18	47.2	73.4	25.0	24.2	55.5	44.5	59.4	48.4
29	2.2	1.6	0	0	3.1	5.5	4.7	0.8
30	23.9	25.0	-	14.1	7.0	-	39.8	33.6
31	6.4	1.6	1.6	1.6	3.1	25.0	9.4	2.3
32	7.7	5.5	3.1	3.1	6.2	15.6	17.2	3.1
33	1.8	2.3	0	0.8	3.1	4.7	1.6	0
37	2.3	0	0	-	2.3	7.8	3.1	0.8
38	7.7	6.2	2.3	3.9	7.0	13.3	15.6	5.5
54	52.8	54.7	-	34.4	46.9	-	74.2	53.9
Mean damage first growing season		15.0	6.3	7.2	12.0	16.1	20.6	12.6
Mean damage 5/6 growing season[a]		5.5	9.0	34.8	24.9	41.2	55.6	29.6

[a] Data from Khalil (1977).

Appendix III. Tallest tree in each replicate among black spruce, Sitka spruce provenances[a].

Replicate (Block)	Height (cm) of Tallest Tree - Each Provenance									
	59	2	4	18	29	31	32	33	37	38
					Crabbes River					
1	551	598	461	478	509	395	478	511	486	(635)*
2	533	423	390	377	(581)	361	486	506	358	463
3	538	527	484	390	(586)	379	400	541	349	486
4	(529)[b]	456	474	374	469	476	414	494	402	404
5	(484)	357	247	226	414	413	424	415	-	470
6	518	572	461	492	465	575	(581)	464	384	515
7	526	402	506	447	499	387	571	(578)	344	521
8	(566)	475	451	492	552	469	452	468	331	405
					Little George's Lake[c]					
1	511	323	(587)	393	527	440	407	482	478	447
2	(458)	430	(458)	360	322	357	454	406	368	407
3	438	398	472	352	297	305	485	(486)	461	271
4	476	436	423	394	465	503	421	448	380	(552)
5	504	542	499	592	482	447	429	505	429	(643)*
6	413	513	447	315	376	445	485	(520)	509	417
7	518	444	436	124	396	(528)	453	493	378	(528)
8	(532)	461	359	254	338	295	484	467	328	417
					Sheffield Lake[d]					
1	560	462	347	394	429	346	509	(577)	325	470
2	397	318	425	245	(585)	367	303	542	379	348
3	(543)	412	434	238	456	209	435	469	309	355
4	544	(600)	296	392	477	389	346	349	375	492
5	535	425	562	378	(576)	460	376	534	328	416
6	462	(601)*	475	287	413	484	429	539	449	421
7	517	(547)	441	343	593	463	423	524	403	438
8	527	468	399	340	545	398	463	471	420	(569)

[a] Provenances 3, 30, 54 not included.

[b] Tallest tree in each replicate in parentheses; tallest tree in plantation with asterik (*).

[c] Seven trees in the surrounds (Provenance 2) were over 500 cm in height and tallest was 587.

[d] 23 trees in the surrounds (Provenance 2) were over 500 cm in height and the tallest was 652.